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PHASE CHANGE/HEAT STORAGE MATERIALS DATA COMPILATION

V. R. HUNTER
R. F. BLOCK
HONEYWELL INC.
AVIONICS DIVISION
ST. PETERSBURG, FLORIDA 33733

JUNE 1979

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AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

TRW, INC.
ONE SPACE PARK
REDONDO BEACH, CALIFORNIA 90278

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This technical report has been reviewed and is approved for publication.

Robert M. Van Vliet

ROBERT M. VANVLIET, Project Engineer
Laser Hardened Materials Branch
Electromagnetic Materials Division

Gary Denman

GARY D. DENMAN, Program Manager
Laser Hardened Materials Branch
Electromagnetic Materials Division

FOR THE COMMANDER

Merrill E. Minges

Dr. Merrill E. Minges
Chief
Electromagnetic Materials Division

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A survey of available phase change heat storage materials for space temperature control applications. A list of thirty one, low-to-medium temperature (100 to 800^{o}F) phase change storage materials are recommended as prime candidates for limiting component temperature excursions during a laser threat. Appendices are provided that include a data compilation of over 200 phase change heat storage materials, a list of data references, a phase

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change material bibliography and more descriptive information on the prime heat storage material candidates.

21. PERFORMING DEPARTMENT

PREFACE

The following is the final report of a survey and data compilation prepared for Honeywell Systems and Research Center in compliance with P.O. 833-808-HA, Task number F0648 AA 0001, for period August 1978 through January 1979.

This work was provided to TRW, Inc., under contract number F33615-78-C-5081, for design application on the SMATH IV development program. Appendix B and C list copyrighted materials used for this survey.

TABLE OF CONTENTS

SECTION I

INTRODUCTION

Dynamic thermal control of a component or critical surface temperature by heat storage techniques can offer unique advantages for some applications. The passive and reliable nature of this approach can be attractive for space applications. Heat storage devices employing phase change materials (PCM) typically offer the highest thermal storage density based on volume or mass. Over 500 potential low melting point (100°C) PCM's have been listed in the literature and even greater numbers of high melting point (300-600°C) PCM's are also candidates. Most of these materials fail to satisfy all the following desirable characteristics for a PCM storage application:

- High Heat of Fusion

  This property defines the available storage energy for the phase change and it may be important on a weight or volume basis.

- Reversible Solid-To-Liquid Transition

  The composition of the solid and liquid phase should be the same. Complete reversibility with no transition hysteresis is desirable.

- High Thermal Conductivity

  This property is usually the key parameter that determines whether a PCM can be successfully applied or not. For space applications, the thermal comductivity is the main driver for transporting the storage energy to and from the solid/liquid interface in the PCM.

- High Specific Heat and Density

  The storage capacity in either the liquid or solid phase can be significant to a given application.

- Long Term Reliability During Repeated Freeze/Thaw Cycling

- Dependable Freezing Behavior

- Low Volume Change During Phase Transition

  This property can greatly complicate the PCM element design. Severe expansions during phase change can cause localized stresses or can require complicated expansion/contraction provisions.

- Low Vapor Pressure

Honeywell has completed a survey of available phase change heat storage materials and has compiled a list of the more attractive prime candidates for space applications. This data compilation is provided to TRW, Inc. for use on the SMATH IV Development Program.

The following Section (II) discusses the heat storage material categories and recommends a list of 31 prime PCM candidate materials. A series of Appendices are also included which contain the following background data.

Appendix A - List of over 200 PCM data.

Appendix B - A PCM data reference list. Scientists at Oak Ridge National Laboratory (ORNL) were consulted to review the list of PCM candidates. Their comments concerning the materials list and their recommendations for additional document reviews are presented in Appendix B.

Appendix C - An extensive heat storage document bibliography.

Appendix D - A compilation of additional descriptive information on some of the prime PCM candidates.

Appendix E - Brief description of the information sources researched in developing the PCM Report.

SECTION II

PHASE CHANGE HEAT STORAGE MATERIALS

Honeywell has conducted a survey of available phase change heat storage materials commonly referred to as PCM's (Phase Change Materials). This data has been obtained from the documents and technical repositories described in Appendices B, C, and E.

The PCM candidates are categorized into ten groups, each category being listed in order of melting points, from low to high.

The accuracy of the data is dependent on the number of significant digits found in the literature. The only exception is in the melting point, where the temperatures were rounded to the nearest integer. Explanatory information (S, L, M, MP) is included when specifically noted in the literature.

When data was not readily available, spaces were left to allow entry of data found at later dates.

Because of the large number of possible phase change materials, the search was limited to materials within the following parameters:

. Transition Temp	100 to 800°F	(40 to 430°C)	
. Heat of Fusion	100,000 to 300,000 J/kg	(24 to 72 cal/gm)	(50 to 150 BTU/lb)
. Density	800 to 6500 kg/m	(.8 to 6.5 gm/cm^3)	(50 to 400 lb/ft^3)
. Specific Heat	500 to 2000 J/kg°K	(.1 to .5 gm/cal/gm-°C)	(.1 to .5 BTU/lb°F)

PARAFFINS

Paraffins normally are of the type C_nH_{2n+2} and have similar properties of the saturated hydrocarbon family. The materials have an intermediate value for latent heat, low thermal conductivity, and are safe. The low thermal conductivity property does limit the paraffins' effectiveness.

Properties of Paraffins:

1) High heat of fusion per unit weight.
2) Wide melting point range (23 to 151°F) which was limited to 100 and above for this search.
3) Flammable.
4) Nontoxic.
5) Noncorrosive.
6) Chemically inert and stable below 932°F.
7) Negligible supercooling behavior.
8) Low volume change on melting.
9) Low vapor pressure in the melt.
10) Density ranges from 43.7 to 48.1 lb/ft .
11) Low thermal conductivity (corrected with fillers).
12) High wetting ability.
13) Predictable and dependable.

NON-PARAFFIN ORGANICS

This category varies widely in the organic materials and their properties. The following factors should be considered in this general category.

- Most are flammable.
- Moderate to high toxicity.
- Many have a low flash point.
- Impurities may greatly affect melting points.
- Many of the long-chain acids show two or more crystalline forms.
- Fillers will improve thermal conductivity.
- Many will decompose when exposed to high temperatures.
- Solid-solid transitions are common.
- Many have high heats of fusion.

METALLICS

This category includes the low melting metals and metal eutectics. Because they are generally so heavy, they are usually not considered as serious prime candidates. On the other hand, they do have high heats of fusion, and high thermal conductivities.

Features of Metallics:

1) Low heat of fusion per unit weight.
2) High heat of fusion per unit volume.
3) High thermal conductivity (fillers not required).
4) Low specific heat.
5) Relatively low vapor pressure.
6) Low expansion of volume on melting.
7) High thermal stability.
8) Minimal hazardous behavior.

INORGANIC SALTS

Inorganic salts are ionic, when dissolved in water they become electrolytes, can be corrosive, and have higher heats of fusion than most of the salts.

The aluminum chloride doubles in volume when melted, but does have some properties that are desirable for thermal storage materials.

$79AlCl_3$ is a fused salt eutectic, that is, a eutectic compound formed by two or more inorganic salts. Fused salt eutectics have the following features:

1) Components can be varied with some eutectics for a choice of values for the melting point and heat of fusion.
2) Generally high heat of fusion.
3) The presence of moisture influences the melting point.
4) Sharp melting point.
5) Corrosive.
6) Aluminum chloride has high volumetric expansion, but is lower in eutectics.

The fluoride salt is a binary compound salt. The addition of impurities lowers the melting point and the heat of fusion. The fusions of fluoride salts generally are reported to occur sharply.

EUTECTICS

A eutectic is an alloy or solution having its components in such proportions that the melting point is the lowest possible with those components. These materials are eutectic mixtures that have not been more specifically categorized.

UREA-BASED EUTECTICS

The urea-based eutectic offers promise as a storage medium. Ammonia chloride forms a simple eutectic-type phase relationship with urea as well as its function as a nucleating agent, solving the problem of supercooling.

SALT HYDRATES

Salt hydrates may be considered alloys of anhydrous salts with a definite number of moles of water forming typical crystalline solids. Salt hydrates usually have incongruent melting points. This is because the solubility is not high enough, and on melting the lower hydrate settles to the bottom. However, there are exceptions when the solubility of the salt is sufficiently high and the solution will dissolve completely in its water of crystallization upon melting and freeze reversibly.

Features of salt hydrates:

1) High heat of fusion per unit weight and volume.
2) Small volume change upon melting.
3) $LiNO_3 \cdot 3H_2O$, $Ba(OH)_2 \cdot 8H_2O$, and $Na_2HPO_4 \cdot 12\ H_2O$ all have congruent melting points.
4) Relatively high thermal conductivity for non-metals.
5) Supercooling, that can be minimized with the addition of nucleating agents.
6) Corrosive.

SOLID-SOLID

The solid state transitions give possibilities for high enthalpies, have low coefficients of thermal expansion, and negligible supercooling. Plastic crystals are organic materials with high transitional enthalpies.

Generally, these organic materials undergo *solid-solid transitions* at a transition temperature below the melting point, where most of the energy is absorbed.

Features of Plastic Crystals:

1) Soft, waxy solids that can be extruded under considerably less pressure than ordinary crystals.
2) High vapor pressures relative to other solids.
3) 10 to 50% volume changes.
4) Minimal supercooling.
5) Fairly high transition temperatures.
6) Generally not very toxic.
7) Non-corrosive.

Appendix A contains a compilation of approximately 200 PCM candidate materials that appear to offer acceptable potential for heat storage applications in satellite components. Table I lists 30 prime candidate heat storage materials that Honeywell recommends for design study as part of the SMATH IV Task 1, Thermo-Materials Analysis. It is hoped that several of these materials can be successfully applied to enhance the survivability of specific satellite components under high energy laser attack environments.

NOTES

Conversations with Dr. Stanley Cantor of ORNL resulted in some minor changes to the prime candidate thermal storage data **(Table 1)**. Adipic acid was added to the prime PCM list and several changes and data additions were incorporated in the table. Dr. Cantor's comments on the PCM survey are summarized below:

1) Many more PCM candidates exist that are not included in the tables, but none of those missed exhibit superior properties over those tabulated.

2) Be aware that gallium and bismuth go through significant density changes during phase change.

3) The urea-based eutectics experience significant ammonia over-pressures above 100°C and decomposition takes place above 135°C.

4) The solid-solid heat of fusion is sometimes not practical because of difficulty of conducting heat through the solid material.

5) Many thermal properties, such as thermal conductivity, specific heat, volumetric expansion, and material stability, have yet to be determined for most storage materials.

The following references were obtained as recommended by Oak Ridge National Laboratory along with resulting information:

1) Janz, George, first author, "Physical Properties Data Compilation Relevant to Energy Storage", Vol. I: Molten Salt Eutectic Data, NSRDS-NBS-61, Part I. Compiled by Molten Salts Data Center, Cogswell Laboratory, Troy, N. Y., March 1978.

   - Verified several melting points of prime PCM candidates.

   - Basically, this is a source to find available references on specific molten salt eutectics.

2) Landolt-Bornstein, "Zahlenwerte Und Funktionen Aus Naturwissenshaften Und Technik", Vol. II, Part 2b, Berlin, Springer, 1961.

   - No new or relevant information found.

3) Lane, G.A., first author, "Solar Energy Subsystems Employing Isothermal Heat Storage Materials", Phase I, September 1974 - April 1975, NTIS-N76-29708, ERDA-117, May 1975.

   - Updated $Ba(OH)_2 \cdot 8H_2O$. Researchers assessed this material's suitability for heat storage as "promising". The results of DTA tests show supercooling, and the freezing curve experiments show little supercooling.

4) Purdue University, "Thermal Physical Properties of Matter", Thermal Physical Properties Research Center, IFI/Plenum, N. Y., 1970.

   - Nothing new found.

   - An excellent source for thermal conductivity data.

TABLE 1

PRIME LOW TEMPERATURE PCM CANDIDATES

REVISED 12/11/78

NAME OR MOLE %	FORMULA	MELTING POINT °K	°C	°F	HEAT OF FUSION cal/gm	BTU/lb	J/Kg x10⁵	HEAT CAPACITY BTU/lb/°F S	L	JOULES/(Kg-°K) x 10³ S	L	DENSITY gm/cm³	lb/ft³	Kg/m³	THERMAL CONDUCTIVITY BTU/Hr - F-ft	Watts/(Meter-°K)	THERMAL EXPANSION COEFF.	SOURCE REFERENCE
PARAFFINS																		
n-Eicosane	$C_{20}H_{42}$	310	37	98	59.0	106	2.46	0.48	0.53	2.0083	2.2175	.856(S) .778^{20}(L)	53.4(S) 48.6(L)	856(S) 778^{20}(L)	0.0865	0.1496	.00029 $°K^{-1}$ (S)	1
n-Hexacosane	$C_{26}H_{54}$	330	56	133	61.0	110	2.56	---	---	---	---	0.770	48.0	770.0	---	---	---	1
n-Tetratria-contane	$C_{34}H_{10}$	346	73	131	64.0	115	2.67	---	---	---	---	---	---	---	---	---	---	6
NON-PARAFFIN ORGANICS																		
Acetic Acid	CH_3 COOH	290	17	62	44.7	80.3	1.87	0.487	0.467	2.040	1.960	1.05^{20} (L)	65.6(L)	1050^{20} (L)	0.104	0.1799	1.071 $°K^{-1}$ (L)	1, 12
Elaidic Acid	$C_8H_7C_9H_{16}$ COOH	320	47	117	52.0	93.7	2.18	---	---	---	---	0.851^{79} (L)	53.1(L)	851^{79} (L)	0.0923	0.1597	---	1, 12
Tristearin	$(C_{17}H_{35}COO)$ C_3H_5	329	56	133	45.6	82.1	1.91	---	---	---	---	0.862^{80} (L)	53.8(L)	862^{80} (L)	---	---	---	1
Oxazoline Wax TS-970	---	347	74	165	DTA estimated		large	---	---	---	---	---	---	---	Estimated quite low		---	1
Acetamide	C_2H_5ON	354	81	178	57.7	104.0	2.42	---	---	---	---	(L&S) 1.159	(L&S) 72.36	(L&S) 1159.0	0.151	M @ 353°K 0.262	---	1, 15
Adipic Acid	HOOC$(CH_2)_4$ COOH	425	152	305	57.8	103.8	2.42	---	---	---	---	---	---	---	---	---	---	ORNL
o-Mannitol	$C_6H_{14}O_6$	439	166	331	70.3	126.1	2.93	0.313	---	0.410	---	1.489^{20}	92.96	1489.0	---	---	---	1, 10
METALLICS																		
Gallium	Ga	303	30	86	19.2	34.4	0.80	0.092	0.091	0.340	0.181	5.903(S) 6.093(L)	368.5 (S) 380.4 (L)	5903.0(S) 6093.0(L)	19.5	33.7	5.8x10^{-5} $°K^{-1}$ (S) 12.0x10^{-5} $°K^{-1}$ (L)	1, 9, 10
---	Li	453	180	356	105.9	190.2	4.42	---	@374°K 1.374	---	5.751	0.53	33.1	530.0	25.43	@523°K 44.0	---	7, 11, 18

KEY

S = SOLID
L = LIQUID
M = MEASURED
MP = MELTING POINT

Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 1

PRIME LOW TEMPERATURE PCM CANDIDATES (Cont'd.)

REVISED 12/15/76

NAME OR MOLE %	FORMULA	MELTING POINT °K	MELTING POINT °C	MELTING POINT °F	HEAT OF FUSION cal/gm	HEAT OF FUSION BTU/lb	HEAT OF FUSION J/Kg x10^5	HEAT CAPACITY BTU/lb/°F S	HEAT CAPACITY BTU/lb/°F L	HEAT CAPACITY JOULES/(Kg-°K) x 10^3 S	HEAT CAPACITY JOULES/(Kg-°K) x 10^3 L	DENSITY gm/cm^3	DENSITY lb/ft^3	DENSITY Kg/m^3	THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL CONDUCTIVITY Watts/(Meter-°K)	THERMAL EXPANSION COEFF.	SOURCE REFERENCE
INORGANIC SALTS																		
---	$AlCl_3$	468	195	351	69.5	124.8	2.90	0.188	---	0.787	---	2.4	149.8	2400.0	---	---	---	1, 7, 11
79-17-4	$AlCl_3$-NaCl -$ZrCl_2$	341	66	154	56.0	101.0	2.35	---	---	---	---	---	---	---	---	---	---	1, 11
---	$LiBF_4$	583	310	558	59.8	107.4	2.50	---	---	---	---	---	---	---	---	---	---	8
EUTECTIC																		
37-61	LiCl - LiOH	535	262	504	104.7	182.0	4.23	0.305	---	1.276	---	@M.P. 1.728	107.9	@M.P. 1728.0	---	---	---	3, 4, 7
95.3 - 4.7	NaOH-Na_2SO_4	566	293	527	78.1	140.3	3.26	---	---	---	---	---	---	---	---	---	---	7
48 - 52	LiF - FeF_2	633	360	680	78.22	140.51	3.27	---	---	---	---	---	---	---	---	---	---	2
UREA-BASED EUTECTIC																		
84 - 16	$CO(NH_2)_2$ - $LiNO_3$	349	76	169	48.4	87.0	2.02	---	---	---	---	---	---	---	---	---	---	5
15.5-84.5	$CO(NH_2)_2$ - $LiNO_2$	386	113	235	51.2	92.0	2.14	---	---	---	---	---	---	---	---	---	---	5
90 - 10	$CO(NH_2)_2$ - NaCl	385	112	234	56.2	101.0	2.35	---	---	---	---	---	---	---	---	---	---	5
SALT HYDRATES																		
Lithium Nitrate Trihydrate	$LiNO_3 \cdot 3H_2O$	303	30	86	70.7	128.0	2.97	0.370	---	1.55	---	1.43(L) 1.55(S)	89.3(L) 96.8(S)	1430(L) 1550(S)	---	---	---	1
Sodium Hydrogen Phosphate Dodecahydrate	$Na_2HPO_4 \cdot 12H_2O$	309	36	97	66.8	120.0	2.79	0.40	0.46	1.6736	1.9246	1.52^{20} (S)	94.9(S)	1520^{20} (S)	.34 (L) 1.69 (S)	.5882(L) 2.9237(S)	$8.3x10^{-5}$ °K^{-1} (S) $43.5x10^{-5}$ °K^{-1} (L)	1, 6
Barium Hydroxide Octahydrate	$Ba(OH)_2 \cdot 8H_2O$	351	82	183	63.5	114.0	2.66	0.28	0.52	1.1715	2.175	2.18	136.0	2180	---	---	---	1, 6

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Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 2

PRIME SOLID-SOLID PCM CANDIDATES

REVISED 12/15/78

NAME OR MOLE %	TRANSITION TEMPERATURE			LATENT HEAT OF TRANSITION			DENSITY			MOLECULAR WEIGHT	MELTING POINT			HEAT OF FUSION			SOURCE REFERENCE
	°K	°C	°F	cal/gm	BTU/lb	J/Kgx10³	cm/gm³	lb/ft³	Kg/m³		°K	°C	°F	cal/gm	BTU/lb	J/Kgx10³	
SOLID-SOLID																	
2-Amino-2-methyl-1-3 Propanediol	351	78	172	63	113	2.63	---	---	---	105.14	352-357	79-84	174-183	7.58	13.6	0.316	1
Pentaerythritol	457	184	363	72	129	3.00	---	---	---	136.15	531	258	496	8.90	16.0	0.372	1

KEY

S - SOLID
L - LIQUID
M - MEASURED
MP - MELTING POINT

Supercripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 3

PRIME HIGH TEMPERATURE PCM CANDIDATES

REVISED
12/15/78

NAME OR MOLE %	FORMULA	MELTING POINT			HEAT OF FUSION			HEAT CAPACITY				DENSITY			THERMAL CONDUCTIVITY		THERMAL EXPANSION COEFF.	SOURCE REFERENCE
								BTU/lb/°F		JOULES/(Kg-°K) x 10³								
		°K	°C	°F	cal/gm	BTU/lb	J/Kg x10⁵	S	L	S	L	gm/cm³	lb/ft³	Kg/m³	BTU/Hr - F-ft	Watts/(Meter-°K)		
40 - 60	KCl - KBr	989	716	1321	58.76	105.55	2.453	---	---	---	---	2.6284	164.09	2828.4	---	---	---	13, 17
40.5 - 59.5	LiF - NaCl	941	668	1234	101.71	182.71^{M}	4.246	---	---	---	---	2.2361	139.60	2236.1	---	---	---	13
42 - 46.5 - 11.5	KF - LiF - NaF	730	457	855	150.43	270.22^{M}	6.280	---	---	---	---	2.5206	157.36	2520.6	---	---	---	13
	LiH	950	677	1250	617.51	1109.2	25.778	---	---	---	---	---	---	---	2.12 (S) 0.7-1.7 (L)	3.669 (S) 1.2-2.9 (L)	---	14
	LiF	1111	838	1558	250.80	450.52	10.470	---	---	---	---	1.8279	$^{M.P.}$ 114.1	1827.9	---	---	---	16

KEY

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M = MEASURED
MP = MELTING POINT

Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

APPENDIX A

STORAGE MATERIALS PROPERTY DATA

TABLE 4

PARAFFINS

NAME	FORMULA	MELTING POINT			HEAT OF FUSION		HEAT CAPACITY BTU/lb/°F		DENSITY		THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/°F	
		°K	°C	°F	cal/gm	BTU/lb	S	L	gm/cm³	lb/ft³			
n-Tetradecane	$C_{14}H_{30}$	279	6	42	54	98	---	---	0.771^{55}	48.1	---	---	
n-Pentadecane	$C_{15}H_{32}$	283	10	50	49	88	---	---	0.768^{20}	47.9	---	---	
n-Hexadecane	$C_{16}H_{34}$	290	17	62	56.67	102.0	---	---	0.774^{20}	48.3	---	---	
n-Heptadecane	$C_{17}H_{36}$	295	22	71	51	92	---	---	0.778^{20}	48.6	---	---	
n-Octadecane	$C_{18}H_{38}$	301	28	82	58	105	---	---	0.774^{20}	48.3	---	---	
n-Eicosane	$C_{20}H_{42}$	310	37	98	59	106	.48	.53	0.778^{20}	48.6(L)	0.0865	.00016	PRIME
n-Heneicosane	$C_{21}H_{44}$	313	40	104	48	86	---	---	0.758^{20}	47.3	---	---	
n-Docosane	$C_{22}H_{46}$	317	44	111	60	107	---	---	0.763^{20}	47.6	---	---	
n-Tricosane	$C_{23}H_{48}$	321	48	118	56	100	---	---	0.764^{20}	47.7	---	---	
n-Pentacosane	$C_{25}H_{52}$	323	49	121	---	---	---	---	0.769	48.0	---	---	
n-Tetracosane	$C_{24}H_{50}$	324	51	123	---	---	---	---	0.766^{20}	47.8	---	---	
Paraffin Wax	---	328	54	130	35	63	.50	.72	0.88	55	---	---	
n-Hexacosane	$C_{26}H_{54}$	330	56	133	61	110	---	---	0.770	48.0	---	---	PRIME
n-Heptacosane	$C_{27}H_{56}$	332	59	138	---	---	---	---	0.773	48.2	---	---	
n-Octacosane	$C_{28}H_{58}$	335	62	143	61	109	---	---	$0.779^{61.1}$	48.6	---	---	
n-Nonacosane	$C_{29}H_{60}$	337	63	146	57	103	---	---	---	---	---	---	
n-Triacontane	$C_{30}H_{62}$	339	65	150	60	108	---	---	---	---	---	---	
n-Hentriacontane	$C_{31}H_{64}$	---	---	---	32.2	57.8	---	---	---	---	---	---	
n-Dotricontane	$C_{32}H_{66}$	343	70	158	---	---	---	---	$0.782^{70.3}$	48.8	---	---	
n-Tritriacontane	$C_{33}H_{68}$	344	71	160	---	---	---	---	---	---	---	---	
Carbowax 1000	---	330	57	103	37.3	67.0	---	.54	1.15	71.8(S)	---	.00042	
n-Tetratriacontane	$C_{34}H_{10}$	346	73	131	64.0	115.0	---	---	---	---	---	---	PRIME
n-Hexatriacontane	$C_{36}H_{74}$	349	76	137	56.2	101.0	---	---	---	---	---	---	

KEY

S = SOLID
L = LIQUID
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MP = MELTING POINT

Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 5

NON-PARAFFIN ORGANICS

NAME	FORMULA	MELTING POINT			HEAT OF FUSION		HEAT CAPACITY BTU/lb/°F		DENSITY		THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/°F	
		°K	°C	°F	cal/gm	BTU/lb	S	L	gm/cm³	lb/ft³			
Myristic Acid, Ethyl Ester	$CH_3(CH_2)_{12}COOC_2H_5$	284	11	52	44	79	---	---	---	---	---	---	
Acetic Acid	CH_3COOH	290	17	62	44.7	80.3	---	---	1.05^{20}	65.6	---	---	PRIME
Glycerin	$CH_2OHCHOHCH_2OH$	291	18	64	47.5	85.3	---	---	1.260^{20}	78.66	---	---	
Polyethylene Glycol 600	$H(OC_2H_2)$ nOH	293-298	20-25	68-77	35	63	---	---	1.1^{20}	69	---	---	
d-Lactic Acid	$CH_3(CH)_2COON$	299	26	79	44	79	---	---	1.249^{15}	77.98	---	---	
Methyl Palmitate	$C_{17}H_{34}O_2$	302	29	84	49	88	---	---	---	---	---	---	
1-3 Methyl Pentacosane	$C_{26}H_{54}$	302	29	84	47	84	---	---	---	---	---	---	
Camphenilone	C_9H_{40}	312	39	102	49	88	---	---	---	---	---	---	
Docasyl Bromide	$C_{22}H_{45}Br$	313	40	104	48	86	---	---	---	---	---	---	
Caprylone	$(CH_3(CH)_2)_6)_2CO$	313	40	104	62	110	---	---	---	---	---	---	
Heptadecanone	$C_{17}H_{34}O$	314	41	106	48	86	---	---	---	---	---	---	
1-Cyclohexylooc-tadecane	$C_{24}H_{48}$	314	41	106	52	93	---	---	---	---	---	---	
4-Heptadecanone	$C_{17}H_{34}O$	314	41	106	47	84	---	---	---	---	---	---	
8-Heptadecanone	$C_{17}H_{34}O$	315	42	108	48	86	---	---	---	---	---	---	
Cyanamide	HNCNH	317	44	111	50	90	---	---	1.08^{20}	67.4	---	---	
Methyl Eicosanate	$C_{21}H_{42}O_2$	318	45	113	55	99	---	---	---	---	---	---	
Elaidic Acid	$C_8H_7C_9H_{16}COOH$	320	47	117	52	93.7	---	---	0.851^{79}	53.1	---	---	PRIME

KEY

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Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 5

NON-PARAFFIN ORGANICS (Cont'd.)

NAME	FORMULA	MELTING POINT °K	MELTING POINT °C	MELTING POINT °F	HEAT OF FUSION cal/gm	HEAT OF FUSION BTU/lb	HEAT CAPACITY BTU/lb/°F S	HEAT CAPACITY BTU/lb/°F L	DENSITY gm/cm³	DENSITY lb/ft³	THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/°F	
Polyethylene Glycol 1000	$H(OC_2H_2)n\ OH$	317-326	44-53	80-95	44.5	80.0	---	---	---	---	---	---	
3-Heptadecanone	$C_{17}H_{34}O$	321	48	118	52	93	---	---	---	---	---	---	
2-Heptadecanone	$C_{17}H_{34}O$	321	48	118	52	93	---	---	---	---	---	---	
Oxazoline Wax - ES-254		323	50	122	---	---	---	---	---	---	---	---	
9-Heptadecanone	$C_{17}H_{34}O$	324	51	124	51	92	---	---	---	---	---	---	
Methyl Behenate	$C_{24}H_{46}O_2$	325	52	126	56	101	---	---	---	---	---	---	
Ethyl Lignocerate	$C_{26}H_{52}O_2$	327	54	129	52	93	---	---	---	---	---	---	
Palmitic Acid	$CH_3(CH_2)_{14}COOH$	328	55	131	39	70	---	---	0.85	53	---	---	
Hypophosphoric Acid	$H_4P_2O_6$	328	55	131	51	92	---	---	---	---	---	---	
Tristearin	$(C_{17}H_{35}COO)_3C_3H_5$	329	56	133	45.6	82.1	---	---	0.862^{80}	53.8	---	---	PRIME
Trimyristin	$(C_{13}H_{27}COO)_3C_3H_3$	306-330	33-57	91-135	48-51	86-92	---	---	---	---	---	---	
Myristic Acid	$C_{14}H_{28}O_2$	331	58	136	47.5	85.5	---	---	0.858^{60}	53.6	---	---	
Ethyl Cerotate	$C_{28}H_{56}O_2$	333	60	140	54	97	---	---	---	---	---	---	
Heptadecanoic Acid	$C_{17}H_{34}O_2$	334	61	141	45.2	81.2	---	---	---	---	---	---	
Stearic Acid	$CH_3(CH_2)_{16}COOH$	343	68	157	47.6	85.5	---	---	0.847^{65}	52.9	---	---	
Oxazoline Wax - TS-970	---	347	74	165	---	---	---	---	---	---	---	---	PRIME

KEY

S = SOLID
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Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 5

NON-PARAFFIN ORGANICS (Cont'd.)

NAME	FORMULA	MELTING POINT			HEAT OF FUSION		HEAT CAPACITY BTU/lb/°F		DENSITY		THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/°F	
		°K	°C	°F	cal/gm	BTU/lb	S	L	gm/cm³	lb/ft³			
Acetamide	C_2H_5ON	354	81	178	57.7	104	---	---	1.159	72.36	---	---	PRIME
Methyl Fumarate	$(CH\ CO_2CH_3)_2$	375	102	216	57.9	104	---	---	1.0452	65.250	---	---	
Resorcinol	$C_6H_4(OH)_2$	383	110	230	---	---	---	---	---	---	---	---	
Succinic Anhydride	$(CH_2CO)_2O$	392	119	246	48.7	87.5	---	---	1.104	68.92	---	---	
Salicylic Acid	HOC_6H_4COOH	432	159	318	47.6	85.5	---	---	1.443	90.09	---	---	
o-Mannitol	$C_6H_{14}O_6$	439	166	331	70.3	126.1	---	---	1.489^{20}	92.96	---	---	PRIME

KEY

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Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 6

METALLICS

NAME	FORMULA	MELTING POINT ^oK	^oC	^oF	HEAT OF FUSION cal/gm	BTU/lb	HEAT CAPACITY BTU/lb/^oF S	L	DENSITY gm/cm^3	lb/ft^3	THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF 1/^oF	
Gallium	Ga	303	30	86	19.2	34.4	---	---	5.903^{2}	368.5	---	---	PRIME
Cerrolow Eutectic	49 Bi + 21 Int 18 Pb + 12 Sn	331	58	136	21.8	39.1	---	---	8.8^{20}	549	---	---	
Cerrobend Eutectic	50.5 Bi + 26.7 Pb + 13.3 Sn + 10.0 Cd	343	70	158	7.78	14.0	---	---	9.4^{solid}	587	---	---	
Bismuth-Lead Indium Eutectic	52 Bi + 26 Pb + 22 In	343	70	158	7.0	13.0	---	---	8-10	500-620	---	---	

KEY

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Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 7

EUTECTIC

COMPOSITION (MOLE %)	FORMULA	MELTING POINT °K	MELTING POINT °C	MELTING POINT °F	HEAT OF FUSION cal/gm	HEAT OF FUSION BTU/lb	HEAT CAPACITY BTU/lb/°F S	HEAT CAPACITY BTU/lb/°F L	DENSITY gm/cm³	DENSITY lb/ft³	THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/°F	
40-7-53	$NaNO_2$ - $NaNO_3$ - KNO_3	430	157	315	29.5	53	.29	.32	@M.P. 1.964	123	.33	---	
50-50	NaOH-KOH	443	170	338	55.8	100	---	---	@M.P. 1.837	114.7	---	---	
54-46	$NaNO_3$ - KNO_3	495	222	432	32.8	58.8	.36	.36	@M.P. 1.96	117	.28(S) .33(L)	---	
70-30	KNO_2 - $NaNO_2$	504	231	447	37.9	68.0^{M}	---	---	@M.P. 1.879	117.3	---	---	
27-73	$NaNO_2$ - NaOH	511	238	460	58.5	105.0^{M}	---	---	@M.P. 1.829	114.2	---	---	
8.1-91.9	$CaCl_2$ - $LiNO_3$	511	238	460	42.9	77.0	---	---	@M.P. 1.831	114.3	---	---	
84.5-15.5	$NaNO_3$ - NaOH	521	248	446	37.9	68.0^{M}	---	---	1.9103	119.3	---	---	
2.6-97.4	$Ba(NO_3)_2$ - $LiNO_3$	525	252	485	87.7	157.5^{M}	---	---	@M.P. 2.133	133.2	---	---	
---	$LiNO_3$	527	254	490	90.7	163.7^{M}	---	---	2.4	149.8	---	---	
23-77	LiOH - NaOH	528	255	460	55.8	100.2	.39	.39	1.9	118.6	---	---	
---	NaCl - $ZnCl_2$	533	260	468	47.4	85.1	---	---	2.5	156.1	---	---	
22.3-77.7	NaBr-NaOH	534	261	500	38.7	69.6^{M}	---	---	@M.P. 2.0195	126.1	---	---	
37-61	LiCl - LiOH	535	262	504	104.7	182.	---	---	@M.P. 1.728	107.9	---	---	PRIME
40.85-59.15	$Ca(NO_3)_2$ - LiCl	538	265	509	40.1	72.0^{M}	---	---	@M.P. 1.868	116.6	---	---	

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Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 7

EUTECTIC (Cont'd.)

COMPOSITION (MOLE %)	FORMULA	MELTING POINT ^oK	^oC	^oF	HEAT OF FUSION cal/gm	BTU/lb	HEAT CAPACITY BTU/lb/^oF S	L	DENSITY gm/cm^3	lb/ft^3	THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/^oF	
40.3-59.7	$CaCl_2$ - $LiNO_3$	541	268	482	43.63	78.37^M	---	---	@M.P. 1.984	123.86	---	---	
6.5-7.4-86.1	Na_2CO_3 - Na_2O NaOH	554	281	505	56.5	101.5^M	---	---	@M.P. 1.8814	117.5	---	---	
7.8-6.4-85.8	NaCl - Na_2CO_3 - NaOH	555	282	508	75.7	136.0	---	---	2.1	131.1	---	---	
8.4-86.3-5.3	NaCl-$NaNO_3$ - Na_2SO_4	560	287	516	42.6	76.4^M	.45	.45	1.993(S) 2.24(S)	140(S) 120.7(L)	.377(S) .377(L)	---	
95.3 - 4.7	NaOH - Na_2SO_4	566	293	527	78.1	140.3	---	---	---	---	---	---	PRIME
4.6 - 95.4	NaCl - $NaNO_3$	570	297	567	46.8	84.0^M	.44	.43	2.3	143.6	.35(S) .35(L)	---	
---	$NaNO_3$	580	307	585	43.5	78.1	.45	.44	2.3(S) 1.9(L)	141(S) 119(L)	.33(S) .35(L)	---	
---	$Na_2N_2O_2$	588	315	567	58.4	104.9	---	---	1.7	106.1	---	---	
45.4-31.9-22.7	KBr-LiCl-$PbBr_2$	596	323	581	40.42	72.61^M	---	---	@M.P. 2.68	167.31	---	---	
39	KCl-LiBr	600	327	620	43.92	78.89	---	---	---	---	---	---	
66.5 (app)	Na_2CO_3 - Na_2SO_4	603	330	626	46.08	82.78	---	---	---	---	---	---	
5.3-44.2-50.5	$CaCl_2$ - KCl - LiCl	605	332	630	62.01	111.38	---	---	---	---	---	---	
5.43-40.92-53.65	$BaCl_2$ - KCl - LiCl	610	337	607	54.63	98.14^M	---	---	.0287	@M.P. 1.793	---	---	

KEY

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Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 7

EUTECTIC (Cont'd.)

COMPOSITION (MOLE %)	FORMULA	MELTING POINT			HEAT OF FUSION		HEAT CAPACITY BTU/lb/°F		DENSITY		THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/°F	
		°K	°C	°F	cal/gm	BTU/lb	S	L	gm/cm³	lb/ft³			
1.8-42.2-56	CaF_2 - KCl - LiCl	611	338	640	65.45	117.57	---	---	---	---	---	---	
5.8-43.3-50.9	CaCl - KCl - LiCl	613	340	644	62.78	112.77	---	---	---	---	---	---	
35-57.5-7.5	KBr-LiCl-NaCl	613	340	644	52.30	93.95	---	---	---	---	---	---	
46.5-56-3.5	KCl-LiCl-LiF	619	346	657	62.63	112.5	---	---	---	---	---	---	
36-55-9	KCl-LiCl-NaCl	619	346	655	67.03	120.40	---	---	---	---	---	---	
42	KCl-LiCl	623	348	627	61.1	109.7	---	---	2.03	126.7	---	---	
21.3-37.7-34.8-6.1	KBr-KCl-LiBr-LiCl	630	357	643	44.26	79.5^{M}	---	---	@M.P. 2.21	137.97	---	---	
39	KBr-LiCl	633	360	680	52.64	94.55	---	---	---	---	---	---	
48-52	LiF-FeF_2	633	360	680	78.22	140.51	---	---	---	---	---	---	PRIME
61-11-28	MnCl -NaCl-NaF	643	370	716	51.13	91.85	---	---	---	---	---	---	
45.5-34.5-5-20	KCl-$MnCl_2$-NaCl	663	390	734	52.43	94.18	---	---	---	---	---	---	
17.8-25.2-2-57	$CaCl_2$-NaCl-$PbCl_2$	664	391	736	28.40	51.02	---	---	---	---	---	---	
---	Li_2CO_3 - K_2CO_3 - Na_2CO_3	666	393	708	66.2	119.0	.40	.39	2.3	143.6	1.17	---	
20-50-30	KCl-$MgCl_2$ - NaCl	669	396	745	69.34	124.55	---	---	---	---	---	---	

KEY

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Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 7

EUTECTIC (Cont'd.)

COMPOSITION (MOLE %)	FORMULA	MELTING POINT ^oK	^oC	^oF	HEAT OF FUSION cal/gm	BTU/lb	HEAT CAPACITY BTU/lb/^oF S	L	DENSITY gm/cm^3	lb/ft^3	THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/^oF
35-17-48	$KCl-NaCl-PbCl_2$	672	399	750	29.57	53.11	---	---	---	---	---	---
37.7-37.3-25	KCl-MnCl - NaCl	673	400	752	53.50	96.11	---	---	---	---	---	---
41.7	$BaCl_2 - Ca(NO_3)_2$	675	402	756	33.41	60.02	---	---	---	---	---	---
3-47-50	$CaCl_2 - KCl - PbCl_2$	675	402	756	28.93	51.97	---	---	---	---	---	---
17.1-28.8-54	$BaCl_2 - CaCl_2$ LiCl	679	406	763	55.37	99.46	---	---	---	---	---	---
48-52	$KCl-PbCl_2$	679	406	763	28.51	51.21	---	---	---	---	---	---
10-90	MgCl - CuCl	679	406	763	46.90	84.24	---	---	---	---	---	---
20	LiCl-CuCl	681	408	766	46.73	83.94	---	---	---	---	---	---
62	$Ba(NO_3)_2$ - NaCl	681	408	766	29.13	52.32	---	---	---	---	---	---
49	$KCl - PbCl_2$	683	410	770	28.89	51.89	---	---	---	---	---	---
46	$LiCl-- PbCl_2$	683	410	770	30.71	55.17	---	---	---	---	---	---
36.1-11.5-52.4	$CaCl_2$ - KCl - LiCl	685	412	774	68.54	123.11	---	---	---	---	---	---
13.8-39.9-46.2	$BaCl_2 - MgCl_2$ -NaCl	691	418	784	56.31	101.15	---	---	---	---	---	---

KEY

S = SOLID
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Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 8

UREA-BASED EUTECTICS

COMPOSITION (MOLE %)	FORMULA	MELTING POINT			HEAT OF FUSION		HEAT CAPACITY BTU/lb/°F		DENSITY		THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/°F	
		°K	°C	°F	cal/gm	BTU/lb	S	L	gm/cm³	lb/ft³			
66-24-10	$CO(NH_2)_2$ - $LiNO_3$	347	74	133	40.6	73.0	---	---	---	---	---	---	
78-16-6	$CO(NH_2)_2$ - $LiNO_3$ - KNO_3	353	80	144	43.8	78.7	---	---	---	---	---	---	
70.7-22.3-7.0	$CO(NH_2)_2$ - $NaNO_3$ - KNO_3	364	91	163	39.2	70.5	---	---	---	---	---	---	
84-16	$CO(NH_2)_2$ - $LiNO_3$	367	94	169	48.4	87.0	---	---	---	---	---	---	PRIME
79-4-17	$CO(NH_2)_2$ - NaCl - $NaNO_3$	369	96	173	45.9	82.5	---	---	---	---	---	---	
77.5-22.5	$CO(NH_2)_2$ - $NaNO_3$	374	101	182	45.3	81.46	---	---	---	---	---	---	
77.9-22.1	$CO(NH_2)_2$ - $NaNO_3$	375	102	183	45.1	81.0	---	---	---	---	---	---	
88.7-8.5-2.8	$CO(NH_2)_2$ - $Ca(NO_3)_2$ - KNO_3	380	107	192	45.9	82.5	---	---	---	---	---	---	
15.5-84.5	$CO(NH_2)_2$ - $LiNO_3$	386	113	203	51.2	92.0	---	---	---	---	---	---	PRIME
89.5-10.5	$CO(NH_2)_2$ - $Ba(NO_3)_2$	387	114	205	41.8	75.0	---	---	---	---	---	---	
82.9-17-1	$CO(NH_2)_2$ - NH_4Cl	392	119	215	50.3	90.4	---	---	---	---	---	---	
85-15	$CO(NH_2)_2$ - KNO_3	400	127	228	50.1	90.0	---	---	---	---	---	---	
90-10	$CO(NH_2)_2$ - NaCl	403	130	234	56.2	101.0	---	---	---	---	---	---	PRIME

KEY

S = SOLID
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M = MEASURED
MP = MELTING POINT

Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 8

UREA-BASED EUTECTICS (Cont'd.)

COMPOSITION (MOLE %)	FORMULA	MELTING POINT			HEAT OF FUSION		HEAT CAPACITY BTU/lb/°F		DENSITY		THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/°F
		°K	°C	°F	cal/gm	BTU/lb	S	L	gm/cm³	lb/ft³		
91-9	$CO(NH_2)_2$ - KCL	406	133	239	55.48	99.65	---	---	---	---	---	---
57.7-23.9-18.3	$CO(NH_2)_2$ - $Ca(NO_3)_2$ - KNO_3	416	143	257	36.8	66.14	---	---	---	---	---	---
74.8-25.2	$CO(NH_2)_2$ - $Ca(NO_3)_2$	431	158	285	43.72	78.53	---	---	---	---	---	---

KEY

S = SOLID
L = LIQUID
M = MEASURED
MP = MELTING POINT

Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 9

FUSED SALT EUTECTICS

NAME	FORMULA	MELTING POINT			HEAT OF FUSION		HEAT CAPACITY BTU/lb/°F		DENSITY		THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF 1/°F	
		°K	°C	°F	cal/gm	BTU/lb	S	L	gm/cm^3	lb/ft^3			
---	31 Na_2SO_4	277	4	39	56	101	---	---	---	---	---	---	
---	79 $AlCl_3$	341	68	154	56	101	---	---	---	---	---	---	PRIME
---	66 $AlCl_3$	343	70	158	50	90	---	---	---	---	---	---	
---	60 $AlCl_3$	366	93	199	51	92	---	---	---	---	---	---	
---	66 $AlCl_3$	366	93	199	48	86	---	---	---	---	---	---	

KEY

S = SOLID
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MP = MELTING POINT

Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 10

SALT HYDRATES

NAME	FORMULA	MELTING POINT			HEAT OF FUSION		HEAT CAPACITY BTU/lb/°F		DENSITY		THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/°F	
		°K	°C	°F	Cal/gm	BTU/lb	S	L	gm/cm³	lb/ft³			
Calcium Chloride Hexahydrate	$CaCl_2 \cdot 6H_2O$	303	29	85	40.7	73.1	---	---	---	---	---	---	
Lithium Nitrate Trihydrate	$LiNO_3 \cdot 3H_2O$	303	30	86	70.7	128.	---	---	1.55^{solid}	96.8	---	---	PRIME
Sodium Hydrogen Phosphate Dodecahydrate	$Na_2HPO_4 \cdot 12H_2O$	309	36	97	66.8	120.	.46	.40	1.52^{20}	94.9	.34(L) 1.69(S)	4.6×10^{-5}	PRIME
Ferric Chloride Hexahydrate	$FeCL_3 \cdot 6H_2O$	310	37	99	54.	97.	---	---	---	---	---	---	
Cobalt Sulfate Heptahydrate	$CoSO_4 \cdot 7H_2O$	314	41	74	40.7	73.1	---	---	---	---	---	---	
---	$Ca(NO_3)_2$ 4-2 moles H_2O	312-315	39-42	102-108	33.	60.	.58	.35	1.82	113.6	---	---	
Ferric Nitrate Enneanydrate	$Fe(NO_3)_3 \cdot 9H_2O$	320	47	117	---	---	---	---	1.684^{20}	105.1	---	---	
---	$Zn(NO_3)_2 \cdot 4W$	321	48	118	68.2	38	---	---	---	---	---	---	
Magnesium Sulfate Heptahydrate	$MgSO_4 \cdot 7H_2O$	322	48	119	48.2	86.6	---	---	---	---	---	---	
Sodium Thiosulfate Pentahydrate	$Na_2S_2O_3 \cdot 5H_2O$	322	49	120	47.9	90	.60	.35	1.69^{solid}	106	---	5.4×10^{-5}	

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MP = MELTING POINT

Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 10

SALT HYDRATES (Cont'd.)

NAME	FORMULA	MELTING POINT			HEAT OF FUSION		HEAT CAPACITY BTU/lb/°F		DENSITY		THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/°F	
		°K	°C	°F	cal/gm	BTU/lb	S	L	gm/cm³	lb/ft³			
---	$Na(NO_3)_2 \cdot 6W$	326	53	127	39.6	71.1	---	---	---	---	---	---	
---	$Co(NO_3)_2$ 6-4 moles H_2O	330	57	135	31.	55.	.50	.37	1.87	116.7	---	---	
---	$MnCl_2$ 4-2 moles H_2O	330	57	136	35.	63.	.57	.35	2.01	125.5	---	---	
Lithium Acetate Dihydrate	$LiC_2H_3O_2 \cdot 2H_2O$	331	58	136	60-90	108-162	---	---	---	---	---	---	
Magnesium Chloride Tetrahydrate	$MgCl_2 \cdot 4H_2O$	331	58	136	42.5	76.3	---	---	---	---	---	---	
---	$Fe(NO_3)_2 \cdot 6W$	332	60	140	30	53.9	---	---	---	---	---	---	
Sodium Hydroxide Monohydrate	$NaOH \cdot H_2O$	338	64	148	65	117	.51	.43	2.13	133.0	.53	---	
---	$Al(NO_3)_3 \cdot 9H_2O$	345	72	130	31.2	56	---	---	---	---	---	---	
Barium Hydroxide Octahydrate	$Ba(OH)_2 \cdot 8H_2O$	351	78	172	72	129	.52	.28	2.18	136	---	---	PRIME
---	$Mg(NO_3)_2 \cdot 6W$	363	90	194	42.6	76.5	---	---	1.64	102.4	---	---	
Aluminum Potassium Sulfate Dodecahydrate	$AlK(SO_4)_2 \cdot 12H_2O$	364	91	196	44	79	---	---	---	---	---	---	
Magnesium Chloride Hexahydrate	$MgCl_2 \cdot 6W$	388	115	239	39.4	70.8	---	---	1.57	98.0	---	---	

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S = SOLID
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Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 11

FLUORIDE SALTS

NAME	FORMULA	MELTING POINT			HEAT OF FUSION		HEAT CAPACITY BTU/lb/°F		DENSITY		THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF. 1/°F	
		°K	°C	°F	cal/gm	BTU/lb	S	L	gm/cm³	lb/ft³			
----	A_SF_6	---	---	---	14.3	25.7	---	---	---	---	---	---	
----	$LiBF_4$	583	310	558	59.8	107.4	---	---	---	---	---	---	PRIME
----	TiF_4	673	400	720	56.5	101.5	---	---	2.8	174.8	---	---	
----	$NaBF_4$	679	406	731	29.6	53.2	---	---	2.53	157.95	---	---	
----	$48RbF/48ZrF_4/4uF_4$	698	425	765	35.0	62.9	---	---	4.19	261.58	---	---	

KEY

S = SOLID
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MP = MELTING POINT

Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 12

MISCELLANEOUS

NAME	FORMULA	MELTING POINT ^{o}K	^{o}C	^{o}F	HEAT OF FUSION cal/gm	BTU/lb	HEAT CAPACITY BTU/lb/^{o}F S	L	DENSITY gm/cm^3	lb/ft^3	THERMAL CONDUCTIVITY BTU/Hr - F-ft	THERMAL EXPANSION SOLID COEFF 1/^{o}F	
Water	H_2O	273	0	32	79.69	143.1	---	---	0.9998^{0}	62.42	---	---	
Transit Heet Series	222-505	222-505	-51-232	-60-450	55-72	99-129	---	---	1.6	100	---	---	
---	Na	371	98	176	---	---	.31	.31	---	---	---	---	
---	Li	453	180	324	105.9	190.2	---	---	5.3	330.9	---	---	PRIME
- ---	$AlCl_3$	468	195	351	69.5	124.8	---	---	2.4	149.8	---	---	PRIME
Draw Salt	---	493	220	396	---	---	.38	.38	---	---	---	---	
---	KNO_3	613	340	612	30.6	55.0	---	---	2.1	131.1	---	---	
---	KOH	673	400	680	33.5	57.6	.32 (S)	.36 (L)	2.04	---	---	---	

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MP = MELTING POINT

Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

TABLE 13

SOLID-SOLID

NAME OR MOLE %	TRANSITION TEMPERATURE			LATENT HEAT OF TRANSITION		DENSITY		MOLECULAR WEIGHT	MELTING POINT			HEAT OF FUSION		
	°K	°C	°F	cal/gm	BTU/lb	Kg/m³	lb/ft³		°K	°C	°F	cal/gm	Btu/lb	
Diaminopenta-erythritol	341	68	154	44	79	---	---	---	---	---	---	---	---	
2-Amino-2-methyl-1, 3 Propanediol	351	78	172	63	113	---	---	105.14	352-357	79-84	174-183.2	7.58	13.6	PRIME
2-methyl-2-nitro-1, 3-propanediol	352	79	174	48	86	---	---	135.12	354-357	81-84	178-183	7.65	13.7	
Trimethylolethane	354	81	178	46	83	1160	72.42	---	---	---	---	---	---	
2-Hydroxymethyl-2-methyl-1,3-propanediol	354	81	178	45	83	---	---	---	470	197	387	11	20	
Monoaminopenta-erythritol	359	86	187	46	83	---	---	---	---	---	---	---	---	
Tris(hydroxymethyl) acetic acid	397	124	255	49	88	---	---	---	---	---	---	---	---	
2-Amino-2-hydroxy-methyl-1,3-propanediol	404	131	268	68	122	---	---	121.14	411-419	138-146	280-295	6.0	10.8	
2,2-bis(hydroxy-methyl) propionic acid	425	152	306	69	124	---	---	134.13	425-428	152-155	305-311	6.41	11.5	
Pentaerythritol	457	184	363	72	129	---	---	136.15	531	258	496	8.90	16.0	PRIME

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Superscripts on values of density refer to the temperature in degrees centigrade at which the density was measured.

APPENDIX B

DATA REFERENCE LIST

1. D.V. Hale, M.J. Hoover, and M.J. O'Neill, "Phase Change Materials Handbook," Lockheed Missiles and Space Company, NASA CR-61363, September 1971.

2. LeFrois, Richard T., Personal Files, "Physico-Chemical and Thermodynamic Properties of Eutectics with Melting Points Between 620-785°F".

3. LeFrois, Richard T., Personal Notes, "Superheater".

4. Venkatasetty, Dr. H.V. and Saathoff, D., Memo: "Theoretical Studies on the Thermo-Physical Properties of Eutectics Suitable for Thermal Storage Subsystem," July 30, 1975.

5. LeFrois, Richard T., and Venkatasetty, Dr. H.V., "A Concept for the Application of Dilute Eutectic - Active Heat Exchange to Low-Temperature Heating and Cooling," Energy Resources Center and Corporate Technology Center, Minneapolis, Minnesota, May 1978.

6. Shelpuk, B., Joy P., and Crouthamel, M., "Technical and Economic Feasibility of Thermal Storage," Final Report, RCA Advanced Technology Laboratories, Camden, New Jersey, June 1976.

7. Tye, R.P., Bourne, J.G., and Desjarles, A.O., "Thermal Energy Storage Material Thermophysical Property Measurement and Heat Transfer Impact," Dynatech R/D Company, NASA CR-135098, August 1976.

8. Eichelberger, J.L., "Investigation of Metal Fluoride Thermal Energy Storage Materials: Availability, Cost and Chemistry", Final Report, Pennwalt Corporation, King of Prussia, Pennsylvania, December 1976.

9. Smithells, Colin J., "Metals Reference Book", Volume II, Butterworths Scientic Publications, London, 1955, p. 636.

10. "Metals Handbook", Volume I - Properties and Selection of Metals, American Society for Metals, Metals Park, Ohio, May 1972, p. 1204.

11. "Handbook of Physics and Chemistry", 43rd edition, The Chemical Rubber Co., 1961-62.

12. "Handbook of Physics and Chemistry", 52nd edition, The Chemical Rubber Co., 1971-72.

13. LeFrois, Richard T., and Venkatasetty, Dr. H.V., "Dilute Eutectic Storage Media for Active Heat Exchange Devices in the Temperature Range of 350 to 1000°C", Honeywell Inc., Minneapolis, Minnesota, June 1978.

14. Honeywell Systems and Research Division, "Solar Heat Source", July 1969, p. 3-98-99.

15. Jamieson, D.T., "Liquid Thermal Conductivity - A Data Survey to 1973", National Engineering Laboratory Compilation, Her Majesty's Stationery Office, 1975.

16. Honeywell Systems and Research Center, "Solar Power", May 1976, p. 4-84.

17. Janz, George J., et al, U.S. Department of Commerce/National Bureau of Standards, "Physical Properties Data Compilations Relevant to Energy Storage", 1. Molten Salts: Eutectic Data, NSRDS-NBS 61, Part 1, March 1978.

18. "American Institute of Physics Handbook", 2nd edition, McGraw-Hill Book Company, Inc., 1963.

APPENDIX C

STORAGE DATA DOCUMENT BIBLIOGRAPHY

1. "American Institute of Physics Handbook", 2nd edition, McGraw-Hill Book Company, Inc., 1963.

2. Belton, Geoffrey, and Ajami, Fouad, "Thermochemistry of Salt Hydrates," University of Pennsylvania and Towne School of Civil and Mechanical Engineering, Philadelphia, Pennsylvania, May 1973.

3. Eichelberger, J.L., "Investigation of Metal Fluoride Thermal Energy Storage Materials: Availability, Cost and Chemistry," Final Report, Pennwalt Corporation, King of Prussia, Pennsylvania, December 1976.

4. Ferrara, A., et al, "Thermal Energy Storage Heat Exchanger," Grumman Aerospace Corporation, NASA CR-135245.

5. Hale, D.V., Hoover, M.J., and O'Neill, M.J., "Phase Change Materials Handbook," Lockheed Missiles and Space Company, NASA CR-61363, September 1971.

6. "Handbook of Physics and Chemistry", 43rd edition, The Chemical Rubber Co., 1961-62.

7. "Handbook of Physics and Chemistry", 52nd edition, The Chemical Rubber Co., 1971-72.

8. Honeywell Corporate Research Center, "Thermal Energy Storage Material Thermophysical Property Measurement and Heat Transfer Model", A Proposal to NASA-Lewis Research Center, Bloomington, Minnesota, May 1975.

9. Honeywell Systems and Research Division, "Solar Heat Source", July 1969, p. 3-98-99.

10. Honeywell Systems and Research Center, "Solar Power", May 1976, p. 4-84.

11. Jamieson, D.T., "Liquid Thermal Conductivity - A Data Survey to 1973", National Engineering Laboratory Compilation, Her Majesty's Stationery Office, 1975.

12. Janz, George J., et al, U.S. Department of Commerce/National Bureau of Standards, "Physical Properties Data Compilations Relevant to Energy Storage", 1. Molten Salts: Eutectic Data, NSRDS-NBS 61, Part 1, March 1978.

13. LeFrois, Richard T., Personal Files, "Appendix A - List of Phase Change Storage Materials".

14. LeFrois, Richard T., Personal Files, "Physico-Chemical and Thermodynamic Properties of Eutectics with Melting Points Between 620-785 F".

15. LeFrois, Richard T., Personal Notes, "Superheater".

16. LeFrois, Richard T., and Venkatasetty, Dr. H.V., "A Concept for the Application of Dilute Eutectic - Active Heat Exchange to Low Temperature Heating and Cooling," Energy Resources Center and Corporate Technology Center, Minneapolis, Minnesota, May 1978.

17. LeFrois, Richard T., and Venkatasetty, Dr. H.V., "Dilute Eutectic Storage Media for Active Heat Exchange Devices in the Temperature Range of 350 to 1000^{o}C", Honeywell Inc., Minneapolis, Minnesota, June 1978.

18. Maru, Hansraj C., et al, "Molten Salt Thermal Storage Energy Storage Systems," Final Report, Institute of Gas Technology, Chicago, Illinois, NASA CR-135419, March 1973.

19. "Metals Handbook", Volume I - Properties and Selection of Metals, American Society for Metals, Metals Park, Ohio, May 1972, p. 1204.

20. Shelpuk, B., Joy P., and Crouthamel, M., "Technical and Economic Feasibility of Thermal Storage," Final Report, RCA Advanced Technology Laboratories, Camden, New Jersey, June 1976.

21. Silverman, M.D., and Engel, J.R., "Survey of Technology for Storage of Thermal Energy in Heat Transfer Salt," ORNL/TM-5682, Oak Ridge National Laboratory, Oak Ridge, Tennessee, January 1977.

22. Smithells, Colin J., "Metals Reference Book", Volume II, Butterworths Scientic Publications, London, 1955, p. 636.

23. Tye, R.P., Bourne, J.G., and Desjarles, A.O., "Thermal Energy Storage Material Thermophysical Property Measurement and Heat Transfer Impact," Dynatech R/D Company, NASA CR-135098, August 1976.

24. Venkatasetty, Dr. H.V. and Saathoff, D.J., Memo: "Thermal Energy Storage Materials Study," Honeywell Corporate Research Center, Bloomington, Minnesota, November 1975.

25. Venkatasetty, Dr. H.V. and Saathoff, D., Memo: "Theoretical Studies on the Thermo-Physical Properties of Eutectics Suitable for Thermal Storage Subsystem," July 30, 1975.

17/5/0000001-00000088// 1

78Y0079165 EDB-78-15 25.060
CHARGING AND DISCHARGING OF LATENT HEAT STORAGE SYSTEMS/
LAMMERS.J./
(DEMAG MATERIALGEWINNUNG.ZWEIBRUECKEN.GER.)
HEMISPHERE PUBLISHING CORP./WASHINGTON.DC/1976/
FUTURE ENERGY PRODUCTION SYSTEMS.HEAT AND MASS TRANSFER PROCESSES.VOLUME 1/
CENTURY.J.C./AFGAN.N.H.(EDS.)/
THE BASIC THERMODYNAMIC AND PHYSICOCHEMICAL CONDITIONS OF LATENT HEAT STORAGE SYSTEMS ARE DISCUSSED AND SOME STORAGE MATERIALS AND THEIR SPECIFIC DATA ARE PRESENTED. SUBCOOLING CAN BE A MAJOR PROBLEM IN THEIR APPLICATION AND CAN BE REDUCED BY ADDING NUCLEATING AGENTS. A GOOD INSULATION OF THE STORAGE UNIT AND A SUITABLE HEAT TRANSPORT SYSTEM ARE ESSENTIAL FOR EFFICIENT OPERATION.THESE TOPICS ARE DISCUSSED WITH RESPECT TO CHARGING AND DISCHARGING./

17/5/0000001-00000088// 4

78C0041955 EDB-78-08 25.060
LATENT HEAT THERMAL ENERGY STORAGE SYSTEMS ABOVE 450/SUP 0/C/
MARIANOWSKI.L.G./MARU.H.C./
(INST.OF GAS TECH..CHICAGO)
AMERICAN NUCLEAR SOCIETY.INC./LA GRANGE PARK.IL/1977/
PROCEEDINGS OF THE 12TH INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE.VOL.1/
THE FEASIBILITY OF STORING THERMAL ENERGY AT TEMPERATURES IN THE 455/SUP 0/TO 535/SUP 0/C (850/SUP 0/TO 1000/SUP 0/F) RANGE IN THE FORM OF LATENT HEAT IS EXAMINED FOR A NUMBER OF INORGANIC SALTS.THE THERMOPHYSICAL PROPERTIES.SAFETY HAZARDS. CORROSIVENESS. AND COST OF OVER 30 SALTS AND SALT MIXTURES ARE EVALUATED AND COMPARED.BECAUSE ALKALI CARBONATE MIXTURES SHOW HIGH THERMAL CONDUCTIVITY. LOW VOLUMETRIC EXPANSION ON MELTING. LOW CORROSIVITY.GOOD STABILITY.AND ACCEPTABLE STORAGE CAPACITIES. THEY ARE ATTRACTIVE AS LATENT-HEAT STORAGE MATERIALS IN THIS TEMPERATURE RANGE.A 35 WT

17/5/0000001-00000088// 6

78J0032208 EDB-78-08 25.060
PROPERTIES OF SOME SALT HYDRATES FOR LATENT HEAT STORAGE/
GAWRON.K./SCHROEDER.J./
(PHILIPS GMBH FORSCHUNGSLABORATORIUM.AACHEN)
INT.J.ENERGY RES./1/4/1977/
351-363/
FOR THE UTILIZATION OF LOW-GRADE HEAT THE LATENT STORAGE OF THERMAL ENERGY IS OF GREAT ADVANTAGE BECAUSE THE HEAT CAN BE PRESERVED AT A CONSTANT TEMPERATURE PERFECTLY MATCHED TO THE SPECIAL PURPOSE OF APPLICATION.INVESTIGATIONS ON THE HEAT CAPACITIES.ENTHALPIES OF FUSION.DENSITIES.CRYSTALLIZATION BEHAVIOR AND OTHER CHEMICAL AND PHYSICAL PROPERTIES HAVE SHOWN THAT THE FOLLOWING SALT HYDRATES ARE ESPECIALLY SUITABLE MEDIA FOR STORING LOW-GRADE HEAT.THE EUTECTIC MIXTURE OF WATER AND 3. 92 PERCENT BY WEIGHT OF SODIUM FLUORIDE.MELTING POINT (MP)'-3.5/SUP 0/C.IS EXTREMELY CONVENIENT AND CHEAP FOR REFRIGERATING OR OTHER COOLING PURPOSES.LITHIUM CHLORATE TRIHYDRATE.LICLO/SUB 3/.3H/SUB 2/O.MP '+8.1/SUP 0/C HAS AN EXTREMELY HIGH STORAGE CAPACITY AND OTHER ADVANTAGEOUS PROPERTIES AS A STORAGE MEDIUM IN COOLING SYSTEMS.BUT A VERY HIGH PRICE WILL LIMIT ITS APPLICATION.CALCIUM CHLORIDE HEXAHYDRATE.CACL/SUB 2/.6H/SUB 2/O.MP '+29.2/SUP 0/C.IS A SUITABLE AND CHEAP STORAGE MEDIUM FOR HEATING PURPOSES.FOR THE SAME APPLICATION DISODIUM HYDROGEN PHOSPHATE DODECAHYDRATE.NA/SUB 2/HPO/SUB 4/.12H/SUB 2/O.MP '+35.2/SUP 0/C.IS EVEN BETTER BECAUSE OF THE LARGER STORAGE CAPACITY PER UNIT VOLUME AND OTHER ADVANTAGES WHICH LARGELY COMPENSATE THE HIGHER MATERIAL COST.THE UNIQUE PROPERTIES OF POTASSIUM FLUORIDE TETRAHYDRATE.KF . 4H / SUB 2 /O.MP '+18.5/SUP 0/C.MAKE IT ESPECIALLY SUITABLE FOR STORING LOW-GRADE HEAT.IT CAN DIRECTLY FUNCTION AS AN ENERGY SINK AND AS AN ENERGY RESERVOIR IN HEAT COLLECTING AND CONSUMING SYSTEMS.EXAMPLES OF THE PRACTICAL APPLICABILITY FOR RESIDENTIAL HEATING.TEMPERATURE LEVELLING AND COOLING ARE DESCRIBED./

17/5/0000001-C000CEE// 8
79A0008765 EDB-78-02 25.060
(COO--2990-6) INVESTIGATION OF METAL FLUORIDE THERMAL ENERGY STORAGE MATERIALS:AVAILABILITY,COST,AND CHEMISTRY.FINAL REPORT,JULY 15,1976--DECEMBER 15,1976/
EICHELBERGER,J.L./
PENNWALT CORP.,KING OF PRUSSIA,PA.(USA).TECHNOLOGICAL CENTER/
DEC 1976/DEP.NTIS,PC A14/MF A01./

STORAGE OF THERMAL ENERGY IN THE 400 TO 1000/SUP 0/C RANGE IS ATTRACTING INCREASING CONSIDERATION FOR USE IN SOLAR POWER, CENTRAL POWER, VEHICULAR, AND COMMERCIAL PROCESS SYSTEMS.THIS STUDY INVESTIGATES THE PRACTICALITY OF USING METAL FLUORIDES AS THE HEAT STORAGE MEDIUM.THE PROJECTED AVAILABILITY OF METAL FLUORIDES HAS BEEN STUDIED AND IS SHOWN TO BE ADEQUATE FOR WIDESPREAD THERMAL STORAGE USE.COSTS ARE PROJECTED AND DISCUSSED IN RELATION TO THERMAL ENERGY STORAGE APPLICATIONS. PHASE DIAGRAMS, HEATS OF FUSION,HEAT CAPACITIES,VAPOR PRESSURES,TOXICITY,STABILITY,VOLUME CHANGES,THERMAL CONDUCTIVITIES,FUSION KINETICS,CORROSION,AND CONTAINER MATERIALS OF CONSTRUCTION FOR A WIDE RANGE OF FLUORIDES HAVE BEEN EXAMINED. ANALYSES OF THESE DATA IN CONSIDERATION OF THERMAL ENERGY STORAGE REQUIREMENTS HAVE RESULTED IN SELECTION OF THE MOST COST-EFFECTIVE FLUORIDE MIXTURE FOR EACH OF 23 TEMPERATURE INCREMENTS BETWEEN 400 AND 1000/SUP 0/C. THERMO-PHYSICAL PROPERTIES OF THESE 23 MATERIALS ARE PRESENTED.COMPARISON OF FLUORIDE WITH NON-FLUORIDE MATERIALS SHOWS THAT THE FLUORIDES ARE SUITABLE CANDIDATES FOR HIGH TEMPERATURE APPLICATIONS ON THE BASES OF COST,HEAT CAPACITY/UNIT VOLUME,HEAT CAPACITY/UNIT WEIGHT,CORROSIVE PROPERTIES,AND AVAILABILITY./

17/5/0000001-C000CEE// 9
78AC007911 EDB-78-02 14.200
(PU--258738) SOLAR ENERGY SUBSYSTEMS EMPLOYING ISOTHERMAL HEAT SINK MATERIALS.FINAL PROJECT REPORT,SEPTEMBER 18, 1974--MARCH 18,1976/
LANE,G.A./BEST,J.S./CLARKE,E.C./GLEW,D.N./KARRIS,G.C./QUIGLEY,S.W./ROSSOW,H.E./
DOW CHEMICAL CO.,MIDLAND,MICH.(USA)/
MAR 1976/DEP.NTIS,PC A04/MF A01./
A GROUP OF OVER 200 POTENTIAL PHASE CHANGE HEAT STORAGE MATERIALS MELTING FROM 10 TO 90/SUP 0/C WAS IDENTIFIED. LABORATORY TESTS NARROWED THESE TO MATERIALS RECOMMENDED FOR HOT FAUCET WATER,HYDRONIC HEATING,FORCED AIR HEATING,HEAT PUMP APPLICATION, RADIANT WALL PANELS, AND STORED COLD SYSTEMS. SEVERAL ENCAPSULATION METHODS WERE STUDIED: MICROENCAPSULATION,ENCAPSULATION OF POWDERS AND GRANULES,AND MACROENCAPSULATION.MICROENCAPSULATION OF CACL/SUB 2/.6H/SUB 2/O IN POLYESTER RESIN HAS BEEN SUCCESSFUL,AND SMALL WALL,FLOOR,AND CEILING PANELS HAVE BEEN PREPARED AND TESTED. MACROENCAPSULATION IN PLASTIC FILM CONTAINERS APPEARS PROMISING FOR HOT AIR SYSTEMS.PRELIMINARY ECONOMIC ANALYSIS STUDIES OF HEATING SYSTEMS BASED ON HEAT-OF-FUSION STORAGE MATERIALS HAVE SHOWN SEVERAL PROMISING APPROACHES./

17/5/0000001-C000CEE// 30
77C0131159 EDB-77-22 14.200
THERMAL STORAGE IN METALS/
BIRCHENALL,C.E./TELKES,M./
(UNIV.OF DELAWARE,NEWARK)
AMERICAN SECTION OF THE INTERNATIONAL SOLAR ENERGY SOCIETY/CAPE CANAVERAL,FL/1976/
SHARING THE SUN:SOLAR TECHNOLOGY IN THE SEVENTIES.VOLUME 8/
BOLER,K.W.(ED.)/
HALIDES AND OXIDES WITH PHASE TRANSFORMATIONS OR EUTECTICS IN THE RANGE OF 200 TO 800/SUP 0/C HAVE BEEN STUDIED AS HEAT STORAGE MATERIALS. SEVERAL ABUNDANT AND CHEAP METALS,NOTABLY AL,CU,MG,SI AND ZN AS BINARY OR MORE COMPLEX ALLOYS, HAVE EUTECTIC TRANSFORMATIONS THAT STORE COMPARABLE OR LARGER AMOUNTS OF HEAT.THEIR HIGH MOLAR DENSITIES YIELD SMALL STORAGE VOLUMES,AND HIGH THERMAL CONDUCTIVITIES SIMPLIFY HEAT TRANSFER.CONTAINMENT SHOULD BE EASIER THAN FOR OXIDES AND HALIDES. THERMODYNAMIC THEORY SHOWS THAT ALLOYS SELECTED FOR HEAT STORAGE SHOULD HAVE HIGHLY DISORDERED EUTECTIC LIQUIDS THAT FREEZE TO WELL-ORDERED,STRONGLY BONDED SOLID PHASES.HEAT STORAGE IN SEVERAL PROMISING BINARY AND TERNARY ALLOYS FOR WHICH DATA ARE AVAILABLE HAS BEEN ESTIMATED AT THREE LEVELS OF APPROXIMATION TO ILLUSTRATE THE APPROACH THAT IS BEING USED TO IDENTIFY SUITABLE SYSTEMS AND THE UNCERTAINTIES THAT NEED TO BE RESOLVED BY ADDITIONAL EXPERIMENTS./

17/5/0000001-C000CEE// 39
77J0068455 EDB-77-12 36.010
THERMODYNAMIC PROPERTIES OF SOLID AND LIQUID METALS AND CERAMICS/
HOCH,M./VERNARDAKIS,T.(CINCINNATI UNIV.,OHIO (USA).DEPT.OF MATERIALS SCIENCE AND METALLURGICAL ENGINEERING)/
HIGH TEMP.- HIGH PRESSURES/8/3/1976/
281-286/
IT HAS BEEN SHOWN EARLIER THAT THE HIGH-TEMPERATURE SPECIFIC HEAT OF SOLIDS CAN BE EXPRESSED AS CSUB(P)' 3NRF(THETASUB(D) /T)+BT +DT/SUP 3/WHERE F(THETASUB(D)/T)IS THE DEBYE FUNCTION.B IS EQUIVALENT TO THE ELECTRONIC SPECIFIC HEAT, AND ANHARMONIC VIBRATIONS WITHIN THE LATTICE CONTRIBUTE ONLY TO D/N IS THE NUMBER OF ATOMS PER MOLECULE.THE SPECIFIC HEAT OF LIQUID METALS AT HIGH TEMPERATURE CAN BE EXPRESSED AS CSUB(P)' 3RF(THETASUB(D)/T)+GT +HT/SUP -2/WHERE G IS THE ELECTRONIC TERM,AND H THE ANHARMONIC TERM.THESE TWO EQUATIONS ARE USED AFTER INTEGRATION TO EXPRESS THE ENTHALPY OF NA, PU, V, AL /SUB 2/O/SUB 3/,AND UO/SUB 2/,OVER A WIDE TEMPERATURE RANGE.IN BOTH SOLID AND LIQUID PHASES,WHERE HEAT CONTENT DATA ARE AVAILABLE/THEY ARE FOUND TO REPRESENT THE DATA VERY WELL.IN ADDITION,HEATS OF FUSION CALCULATED WITH THE USE OF THE EQUATIONS ARE IN VERY GOOD AGREEMENT WITH EXPERIMENTAL VALUES.THE SECOND OF THE TWO EQUATIONS CAN ALSO BE USED TO ESTIMATE THE HIGH-TEMPERATURE SPECIFIC HEAT FOR OTHER LIQUID METALS AND CERAMICS WHERE AVAILABLE DATA ARE SCARCE./

DOE ABSTRACTS (continued)

17/5/0000001-C0000EE// 78
76H0000634 EDP-76-01 25.060
(ERDA--59)SURVEY AND SELECTION OF INORGANIC SALTS FOR APPLICATION TO THERMAL ENERGY STORAGE/
BORUCKA.A./
BORUCKA RESEARCH CO..LIVINGSTON.N.J.(USA)/
JUN 1975/DEP.NTIS $5.45./

17/5/0000001-C0000EE// 81
75H0018780 EDP-75-05 40.030
(AD--785481) THERMODYNAMIC PROPERTIES OF ORGANIC COMPOUNDS AND THERMODYNAMIC PROPERTIES OF FLUIDS.FINAL TECHNICAL SUMMARY REPORT.16 OCTOBER 1973--30 JUNE 1974/
DOUSLIN.D.R./GOOD.W.D./FINKE.H.L./MESSERLY.J.F./OSBORN.A./
BUREAU OF MINES.BARTLESVILLE.OKLA.(USA).BARTLESVILLE ENERGY RESEARCH CENTER/
JUN 1974/NTIS $3.00./

3/5/1
ID NO.- EI760210021 610021
THERMAL ENERGY STORAGE.
TELKES, MARIA
UNIV OF DEL, NEWARK
INTERSOC ENERGY CONVERS ENG CONF, 10TH, REC, UNIV OF DEL, NEWARK, AUG 18-22 1975 PAP 759020 P 111-115. PUBL BY IEEE (CAT N 75CHO 983-7 TAB), NEW YORK, NY, 1975
DESCRIPTORS: (*HEATING, *SOLAR),
IDENTIFIERS: ENERGY STORAGE
CARD ALERT: 643
VARIOUS THERMAL STORAGE MATERIALS ARE COMPARED AND THEIR THEORETICAL AND ACTUAL PERFORMANCE LIMITATIONS ARE SUMMARIZED. SOLID/LIQUID PHASE CHANGE REACTIONS (HEAT OF FUSION MATERIALS, OR HEAT SINKS) ARE DESCRIBED, ESPECIALLY IN SOLAR HEATING APPLICATIONS. INEXPENSIVE MATERIALS ARE AVAILABLE THAT ARE NONTOXIC, NOT CORROSIVE AND NOT COMBUSTIBLE. THE PROBLEMS OF SUPERCOOLING, OR OF UNWANTED LABILE CRYSTAL FORMS CAN BE CONTROLLED BY HETEROGENEOUS NUCLEATING MATERIALS OR DEVICES. RESULTS ARE PRESENTED WITH SODIUM THIOSULFATE PENTAHYDRATE MELTING AROUND 49 $DEGREE$ C, (120 $DEGREE$ F). 14 REFS.

12/5/3
ID NO.- EI770316618 716618
THERMAL ENERGY STORAGE UNIT BASED ON LITHIUM FLUORIDE.
ASSELMAN, G. A. A.
PHILIPS RES LAB, EINDHOVEN, NETH
ENERGY CONVERS V 16 N 1-2 1976 P 35-47 CODEN: ENERBS
DESCRIPTORS: *ENERGY STORAGE,
CARD ALERT: 901
A THERMAL ENERGY STORAGE UNIT EMPLOYING LITHIUM FLUORIDE HAS BEEN BUILT TO SUPPLY HEAT TO A STIRLING ENGINE. THE HEAT TRANSPORT FROM THE ELECTRIC HEATING ELEMENTS TO THE HEAT STORAGE UNIT AND FROM THE LATTER TO THE HEAT SINK IS AFFECTED BY THE EVAPORATION AND CONDENSATION OF SODIUM. THE LIQUID SODIUM IS TRANSPORTED WITH THE AID OF CAPILLARY STRUCTURES, SO THAT THE SYSTEM OF HEAT TRANSFER HAS THE CHARACTERISTICS OF A HEAT PIPE. ALL THE EXPERIMENTS WERE CONDUCTED WITH LITHIUM FLUORIDE AS THE HEAT-ACCUMULATION MATERIAL. MUCH CHEAPER MATERIALS WITH PRACTICALLY THE SAME PROPERTIES ARE NOW AVAILABLE. THE EXPERIENCE GAINED WITH THE STORAGE UNIT BUILT COMBINED WITH LATER DEVELOPMENTS IN THE HEAT-PIPE FIELD AND IN THE USE OF ANTI-CORROSION INHIBITORS FOR THE SALT, HAVE LED TO MORE SOPHISTICATED DESIGNS, WHICH ARE DESCRIBED. 9 REFS.

N72-14503# Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.
THE EFFECT OF CONCENTRATED ENERGY FLUXES ON MATERIALS
Yu. L. Krasulin, N. N. Rykalin, and M. Kh. Shorshorov 12 Jul. 1971 17 p refs Transl. into ENGLISH from Fiz. Khim. Obrab. Mater. (Moscow), no. 4, 1967 p 5-10
(AF Proj. 7JJ)
(AD-730079; FTS-HT-23-887-71; PIA-Task-T66-01-8) Avail: NTIS CSCL 13/8

The article is an examination of the peculiarities and the mechanism of the effect of concentrated energy sources on materials (electron beam, laser beam, shock waves of explosives and electrical explosion of wires) with various forms of treatment (cutting, dimensional machining, melting, welding, deforming, strengthening, the application of coatings). Special attention is given to pulse effect. Trends of future investigations in this region are examined. Author (GRA)

N73-25969*# Teledyne Brown Engineering, Huntsville, Ala. Science and Engineering.
HANDBOOK ON PASSIVE THERMAL CONTROL COATINGS Final Report
T. K. Mookherji and J. D. Hayes Apr. 1973 155 p refs
(Contract NAS8-25900)
(NASA-CR-124287; SE-SSL-1717) Avail: NTIS HC $9.75 CSCL 11C

A handbook of passive thermal control surfaces data pertaining to the heat transfer requirements of spacecraft is presented. Passive temperature control techniques and the selection of control surfaces are analyzed. The space environmental damage mechanisms in passive thermal control surfaces are examined. Data on the coatings for which technical information is available are presented in tabular form. Emphasis was placed on consulting only those references where the experimental simulation of the space environment appeared to be more appropriate.
Author

N74-31980# Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.
PRESSURE PRODUCED BY VAPORIZATION AS A MECHANISM FOR REMOVING MELT FROM A TARGET SUBJECTED TO LASER RADIATION M.S. Thesis
Martin M. Bittner Mar. 1974 139 p refs
(AD-780631; GAW/MC/74-11) Avail: NTIS CSCL 20/5

An analysis was made of the effect of pressure generated by vaporization of the surface of a thin slab irradiated with a high intensity laser beam. A finite element analysis was used to obtain numerical solutions of the heat and flow equations, and a computer program was developed to perform the required calculations. Titanium and aluminum slabs 0.08 and 0.127 cm thick were analyzed for response to pressure effects using peak absorbed intensities of 10,000 to 140,000 watts/sq cm. Pressures in the low pressure regime were predicted by the model, and the model predicted that melt removal afrom the area of flux incidence occurred. The most significant effect was a reduction in time required to melt the rear surface of the slab over the time computed on a strictly two dimensional heat flow analysis. Slab thickness, material properties, and peak absorbed intensities all contributed to the overall effect. Author (GRA)

N76-20208# Stuttgart Univ. (West Germany). Dept. of Energy Conversion and Heat Transfer.
DESIGN, DEVELOPMENT AND SPACE QUALIFICATION OF A PROTOTYPE PHASE CHANGE MATERIAL DEVICE Final Report
A. Abhat Oct. 1975 118 p refs
(Contract ESTEC-2331/74-AK)
(ESA-CR(P)-757) Avail: NTIS HC $5.50

The small prototype PCM (Phase Change Material) device designed for spacecraft thermal control and having a latent storage capacity of 100 watt hours, is a hermetically sealed unit made from aluminum alloy, filled with octadecane serving as the PCM and uses aluminum honeycomb structure as the filler material. The overall weight of the device is approximately 2,400 gm. A thermal network model was successfully developed to design the PCM device and predict its thermal performance under different heat load conditions. Experiments were done following construction of the prototype PCM device to obtain actual performance data and to prove its ability to withstand the space qualification procedures. Experimental data indicated the device to be well suited for the desired space applications. Comparison between theory and experiments showed good agreement. Author (ESA)

N76-15842# Lehigh Univ., Bethlehem, Pa. Dept. of Geological Sciences.
ENERGY STORAGE USING LATENT HEAT OF PHASE CHANGE. 1: HYDRATES OF DISODIUM PHOSPHATE. 2: PROTOTYPE STORAGE RESERVOIR Final Report, 1 Jun. 1974 - 31 Jul. 1975
Dale R. Simpson 31 Jul. 1975 51 p refs
(Grant NSF P-416180-000)
(PB-244756/3; NSF/RANN/SE/P416180-00/FR-75-1; NSF/RA/N-75-064) Avail: NTIS HC $4.50 CSCL 10B

This report presents results of experiments and models for thermal energy storage using solution and precipitation of hydrates of disodium phosphate. The research was restricted to solutions having a sodium phosphate ratio from 2:1 to 1.4:1 and the temperature range of 10 to 60C. Solution density and pH was determined as a function of composition and temperature, and the large range in values makes the measurements useful as a monitoring technique. Solubility isotherms were experimentally established in order to establish the solution with the highest yield of material undergoing a phase change. Data on a previously unreported hydrate is presented. The latent heat for the phase change of the dodecahydrate is about 100 cal/cc. The heat capacity and thermal conductivity of selected solutions and crystals are reported. By using a non-stoichiometric solution and a process of precipitation and solution, in contrast to incongruent melting, the composition selected was cycled without degradation. The reservoir design is based on the concept of a vertical thermal stratification and the maintenance of seed crystals. GRA

N77-12510*# Dynatech R/D Co., Cambridge, Mass.
THERMAL ENERGY STORAGE MATERIAL THERMOPHYSICAL PROPERTY MEASUREMENT AND HEAT TRANSFER IMPACT
R. P. Tye, J. G. Bourne, and A. O. Desjarlais 11 Aug. 1976 98 p refs
(Contract NAS3-19716)
(NASA-CR-135098; Rept-1503) Avail: NTIS HC A05/MF A01 CSCL 10A

The thermophysical properties of salts having potential for thermal energy storage to provide peaking energy in conventional electric utility power plants were investigated. The power plants studied were the pressurized water reactor, boiling water reactor, supercritical steam reactor, and high temperature gas reactor. The salts considered were LiNO3, 63LiOH/37 LiCl eutectic, LiOH, and Na2B4O7. The thermal conductivity, specific heat (including latent heat of fusion), and density of each salt were measured for a temperature range of at least + or - 100 K of the measured melting point. Measurements were made with both reagent and commercial grades of each salt. Author

N77-31831# Oak Ridge National Lab., Tenn.
LOW TEMPERATURE THERMAL ENERGY STORAGE Quarterly Progress Report, Jul. - Sep. 1976
H. W. Hoffman and R. J. Kedl 31 Jan. 1977 23 p
(Contract W-7405-eng-26)
(ORNL/TM-5795) Avail: NTIS HC A02/MF A01

At ORNL, research efforts were continued to (a) develop a time-dependent analytical model that will describe a TES system charged with a phase change material, (b) measure thermophysical properties and melt-freeze cyclic behavior of interesting PCM's and (c) determine crystal lattice structures of hydrated salts and their nucleators. A report on TES subsystems for application to solar energy sources was completed and is being reviewed. In the area of program management, subcontracts were signed. Detailed reviews were completed for ten unsolicited proposals related to TES. Industries, research institutions, universities and other national laboratory participation in the TES program, for which ORNL has management responsibilities are listed. ERA

TAB INDEX

AD-B019 292L Fld. 22/2, 11/3, 20/3
GENERAL ELECTRIC CO PHILADELPHIA PA SPACE DIV
CONDUCTIVE COATINGS FOR SATELLITES. (U)
Final rept. 15 May 75-30 Jun 76,
by Allen E. Eagles and Victor J. Belanger. Dec 76, 89p. Rept. no. 76SDS-4275
Contract F33615-75-C-5267, Proj. 7340, Task 07
AFML-TR-76-233

Unclassified report

Distribution limited to U.S. Gov't. agencies only; Test and Evaluation; Dec 76. Other requests for this document must be referred to Director, Air Force Materials Lab., Attn: MBE, Wright-Patterson AFB, Ohio 45433.

Descriptors: *Silicon dioxide, *Thermal insulation, *Ceramic coatings, *Synchronous satellites, *Electrostatic charge, Control, Protective coatings, Space technology, Electrical properties, Optical properties, Ceramic fibers, Secondary emission, Sizing, Removal, Test methods

AD-B019 633L Fld. 22/2, 20/3, 11/3
IIT RESEARCH INST CHICAGO ILL
ELECTRICALLY CONDUCTIVE PAINTS FOR SATELLITES. (U)
Final rept. 16 Feb-15 Sep 76,
by J. E. Gilligan, T. Yamauchi, Richard E. Wolf and Charles Ray. Dec 76, 117p. Contract F33615-76-C-5250, Proj. 7340, Task 07
AFML-TR-76-232

Unclassified report

Prepared in cooperation with Desoto Chemical Co., Inc., Des Plaines, Ill.

Distribution limited to U.S. Gov't. agencies only; Test and Evaluation; Dec 76. Other requests for this document must be referred to Director, Air Force Materials Lab., Attn: MBE, Wright-Patterson AFB, Ohio 45433.

Descriptors: *Electrical conductivity, *Polymers, *Plastic paints, *Electrostatic charge, Organic compounds, Artificial satellites, Spacecraft, Thermal properties, Coatings, Reflectivity, Charged particles, Electrical measurement

AD-B022 969L Fld. 11/3, 22/2, 11/2, 11/5
GENERAL ELECTRIC CO PHILADELPHIA PA SPACE DIV
FABRIC COATINGS FOR SATELLITE TEMPERATURE CONTROL. VOLUME I. (U)
Final rept. 1 Jan-31 Dec 76,
by Allen E. Eagles. May 77, 159p. Rept. no. 77SDS4211-Vol-1
Contract F33615-76-C-5067, Proj. 7340, Task 07
AFML-TR-77-65-Vol-1

Unclassified report

See also Volume 2, AD-B022 970L.

Distribution limited to U.S. Gov't. agencies only; Test and Evaluation; May 77. Other requests for this document must be referred to Director, Air Force Materials Lab., Attn: MBE, Wright-Patterson AFB, OH 45433.

Descriptors: *Thermal insulation, *Silicon dioxide, *Fabrics, *Coatings, *Spacecraft, Thermal properties, Optical properties, Temperature control, Emittance, Hemispheres, Test methods, Space simulation chambers, Processing, Cleaning, Solvents, Electronic scanners, Scanning electron microscopy, Space technology, Adhesive bonding, Solar radiation, Reflection

AD-B022 970L Fld. 11/3, 22/2, 11/5
GENERAL ELECTRIC CO PHILADELPHIA PA SPACE DIV
FABRIC COATINGS FOR SATELLITE TEMPERATURE CONTROL. VOLUME II. DESIGN HANDBOOK. (U)
Final rept. 15 Jan-31 Dec 76,
by Allen E. Eagles. 1 May 77, 38p. Rept. no. 77SDS4211-Vol-2
Contract F33615-76-C-5067, Proj. 7340, Task 07
AFML-TR-77-65-Vol-2

Unclassified report

See also Volume 1, AD-B022 969L.

Distribution limited to U.S. Gov't. agencies only; Test and Evaluation; May 77. Other requests for this document must be referred to Director, Air Force Materials Lab., Attn: MBE, Wright-Patterson AFB, OH 45433.

Descriptors: *Thermal insulation, *Fabrics, *Coatings, *Spacecraft, *Handbooks, Thermal properties, Optical properties, Temperature control, Emittance, Absorption, Solar radiation, Processing, Degradation, Thermal cycling tests, Electrostatic charge, Radiofrequency, Transmission, Bonding, Environmental tests

APPENDIX D

DESCRIPTIVE INFORMATION ON PRIME PCM CANDIDATES

n-EICOSANE

FORMULA: $C_{20}H_{42}$

MATERIAL COMPATIBILITY: Compatible with most structural materials.

SUPERCOOLING: None observed.

HAZARDS: Flammability: fire hazard is present when exposed to flame, high temperatures or strong oxidizing materials.

Toxicity: generally non-toxic.

OTHER: Non-corrosive, reliable and predictable.

ELAIDIC ACID

FORMULA: $C_8H_7C_9H_{16}COOH$

MATERIAL COMPATIBILITY: Compatible with aluminum

SUPERCOOLING: None observed

HAZARDS: Mild toxicity; non-corrosive

OTHER: Exhibits good freezing behavior

ACETIC ACID

FORMULA: CH_3COOH

MATERIAL COMPATIBILITY:

Metals - Generally does not attack aluminum, stainless steel, silver and other precious metals, titanium, tantalum, and zirconium. It reacts with magnesium, nickel and nickel alloys, tin, copper and copper alloys, beryllium, chromium, zinc, in varying degrees.

Nonmetals - Compatible with fluorocarbons (TFE, FEP) graphite, glass-ceramics. Reacts with acrylics, rubbers, epoxys, nylon and phenolics.

VOLUMETRIC EXPANSION DURING PHASE CHANGE: +15.6% on melting

SUPERCOOLING: One phase supercooling of about 15°K, 27°F, 15°C

HAZARD CHARACTERISTICS:

Flash Point: 313°K (104°F, 40°C)

Autoignition Temp: 839°K (1050°F, 566°C)

Flammability: Moderate, when exposed to heat or flame; can react vigorously with oxidizing materials.

Toxicity: Caustic, irritating. When heated to decomposition, it emits toxic fumes.

TRISTEARIN

FORMULA: $(C_{17}H_{35}COO)_3\ C_3H_5$

MATERIAL COMPATIBILITY: Compatible with aluminum.

SUPERCOOLING: None observed.

CHARACTERISTICS: On further heating after melting point, solidifies and melts again at $345^{\circ}K$. No unusual freezing behavior is noted.

OTHER: Non-corrosive and non-toxic.

OXAZOLINE WAX - TS-790

MATERIAL COMPATIBILITY: Very inert and consequently compatible with many materials. Exhibits container separation with quartz and pyrex.

SUPERCOOLING: None observed.

HAZARDS: Flammability: probably flammable.

OTHER: Thermal diffusivity estimated very low.

ACETAMIDE

FORMULA: C_2H_5ON

MATERIAL COMPATIBILITY: Compatible with aluminum.

VOLUMETRIC EXPANSION DURING PHASE CHANGE: +8.15% on melting.

SUPERCOOLING: None observed.

HAZARDS: Toxicity: emits toxic cyanide fumes when heated to decomposition.

OTHER: Good thermal diffusivity.

GALLIUM

MATERIAL COMPATIBILITY: Very corrosive.

VOLUMETRIC EXPANSION DURING PHASE CHANGE: -3.2% (Volume decreases with melting).

SUPERCOOLING: Up to 30°K, depending on purity. Very pure gallium supercools as much as 30°K, whereas impure gallium may not, depending upon the type of impurity. The presence of lithium and bismuth tend to substantially decrease supercooling. Cerium, copper, and molybdenum produce a small decrease in supercooling. Antimony, sodium, lead, silicon, and cadmium support supercooling.

CHARACTERISTICS: Excellent physical and chemical stability. Expands on freezing. Thermally stable.

LITHIUM NITRATE TRIHYDRATE

FORMULA: $LiNO_3 \cdot 3H_2O$

MATERIAL COMPATIBILITY: Compatible with aluminum, quartz, pyrex . Possibility of corrosion on long-term contact.

VOLUMETRIC EXPANSION DURING PHASE CHANGE: +8%

SUPERCOOLING: Without a catalyst, up to 30°K of supercooling can be expected. $Zn(OH)NO_3$ has been reported as an effective catalyst.

HAZARDS: An effective nucleating catalyst has been reported, which prevents supercooling. Because of coordinated water of hydration, $LiNo_3 \cdot 3H_2O$ doesn't exhibit hazardous behavior typical of anhydrous salts.

SODIUM HYDROGEN PHOSPHATE DODECAHYDRATE

FORMULA: $Na_2HPO_4 \cdot 12H_2O$

MATERIAL COMPATIBILITY: Corrosive to aluminum

VOLUMETRIC EXPANSION DURING PHASE CHANGE: +5.1%

SUPERCOOLING: None observed

OTHER: Melts congruently. Use of inhibitors such as sodium silicate (water glass) should overcome corrosion problems.

BARIUM HYDROXIDE OCTAHYDRATE

FORMULA: $Ba(OH)_2 \cdot 8H_2O$

MATERIAL COMPATIBILITY: Corrosive to aluminum

HAZARDS: No particular hazards, due caution with human contact.

OTHER: Melts congruently with negligible supercooling.

APPENDIX E

SOURCES RESEARCHED IN PERFORMING THERMO-MATERIALS TASK

1. Personal files of Mr. Richard LeFrois
   Thermal Storage Staff Engineer
   Honeywell Energy Resources Center
   Minneapolis, Minnesota

2. Personal files of Dr. H.V. Venkatasetty
   Thermal Storage Researcher
   Honeywell Corporate Technology Center
   Minneapolis, Minnesota

3. Phase Change Materials Handbook, NASA CR-61363

4. Avionics Division Library

   TAB 1971 through 1978
   STAR 1971 through 1978
   St. Petersburg, Florida

5. Energy Resources Center Library, Minneapolis, Minnesota

6. Corporate Technology Center Library, Minneaplis, Minnesota

<u>Professional Library Computer Search Services:</u>

7. State Technology Applications Center (STAC)
   NASA-Florida
   University of South Florida
   Tampa, Florida

8. Energy Resources Center Library
   DOE Energy Abstracts
   Minneapolis, Minnesota

9. Avionics Division Library
   Defense Documentation Center Search
   (Low Temperature Storage/Satellites)
   St. Petersburg, Florida

*U.S. Government Printing Office: 1979 — 657-084/252